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OPERATION SNAPPER

Project 8.1

EFFECTS OF ATOMIC EXPLOSIONS ON FOREST FUELS

REPORT TO THE TEST DIRECTOR

by

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Forest Service

ABSTRACT

Project 8.1 was designed to determine minimum thermal energies required to ignite common forest fuels, to determine blast-wave effect on persistence of ignition, and to provide field data against which laboratory source tests could be scaled.

Prepared fuel beds of conifer needles, hardwood leaves, grasses, and rotten wood were exposed in Operation SNAPPER to total energies varying from 1 to 22 cal/sq cm. Thickness and density of fuel particles were determined prior to the test. Fuel moisture at shot time was measured in duplicate fuel beds, similarly located but outside the test area.

Post-test fuel examinations showed that punky materials and fine grasses ignited and continued to burn at distances from ground zero where total thermal energy was approximately 3 cal/sq cm. Following Shots 3 and 4 punky materials were still burning upon recovery at H+2 hours.

Conclusions based on results and observations from Operation SNAPPER:

1. The following conclusion from Operation BUSTER was confirmed over a wider range of fuel types: "Under fire weather conditions1/ in a forest area atomic explosions can be expected to ignite punky and fine grassy fuels wherever total thermal energy2/ exceeds 3 cal/sq cm."

2. Minimum ignition energies have been established approximately within plus or minus 10 per cent for common wildland fuels — pine needles, hardwood leaves, grasses, and punky materials.

3. SNAPPER results and laboratory tests indicate that no more large-scale forest-fuel effects tests are required for bombs with thermal-pulse times of the order encountered in BUSTER and SNAPPER shots.

4. Punky materials and fine grasses which are ignited at low energy levels by atomic explosions can spread fire to associated fuels which would not otherwise have been ignited.

1/ Relative humidity less than 40 per cent, air temperature greater than 35° F, fuel moisture less than 15 per cent.
2/ Pulse shapes similar to those of BUSTER and SNAPPER shots.

5. Sparse tree crowns exposed as at Operation SNAPPER to energies of 22 cal/sq cm effectively shade dead surface fuels so that few ignitions of these fuels can occur in their shadows. Dense, green forest stands with 100 per cent crown closure should offer few if any ignitible points where persistent ignition and fire would occur following atomic explosions.

6. Minimum thermal energies from atom bombs required to ignite wildland fuels can be approximated by laboratory source tests when corrections are made for pulse shape and spectral distribution.

7. Probability that ignitions will occur when fuels are placed where they receive the minimum thermal energy required for ignition depends on moisture content, thickness, specific weight, and arrangement of fuel particles in the fuel bed.

CONTENTS

ILLUSTRATIONS

TABLES

EFFECTS OF ATOMIC EXPLOSIONS ON FOREST FUELS

1.0 OBJECTIVE

Project 8.1, Operation SNAPPER, part of an over-all study of consequences of atomic explosions on forests, sought:

1. To determine minimum thermal energies required to ignite common forest fuels.

2. To provide field data against which subsequent laboratory-thermal-source tests may be scaled and analyses checked.

3. To determine blast-wave effect on persistence of ignition.

Data from this project are important to offensive and defensive military operations in wildland areas and to civilian defense activities in urban and rural areas. After atomic bomb energies are dissipated, the probability of fire storms or of conflagration-type fires is determined by the number of persistent ignitions, forest fuel conditions, and weather conditions.

2.0 HISTORICAL AND THEORETICAL

Preliminary analyses3/ predicted distances from ground zero at which thin forest fuels might be ignited by thermal radiation from atomic bombs. Recent work4/ showed that more accurate analytical predictions of persistent ignition were impossible until mechanics of the ignition process is better understood, and until more accurate determinations of certain basic thermal properties of fuels are made.

Consequently, for the present, field tests and laboratory source tests must be employed to obtain more accurate and more widely applicable predictions of thermal effects.

Field tests in connection with Operation BUSTER established preliminary thermal energy requirements for persistent ignition of some forest fuels. Laboratory tests using the Forest Service 12-in. source at the University of California at Los Angeles have been conducted on these fuels and on fuels exposed during Operation SNAPPER.

3/ Operations Research Office. Preliminary Study of the Consequences of an Atomic Explosion Over a Forest. ORO-T-108. Washington, 1950. 102 pp.

4/ Armed Forces Special Weapons Project—Forest Service interim technical report, to be published. "Thermal Determinants Which Affect Probabilities of Persistent Ignition."

TABLE 1

Thermal Energies Which Produced Persistent Ignition of Forest Fuels During Operation BUSTER

Fuel	Moisture Content (Per Cent)	Total Energy (Cal/sq/cm)		
		Not Established as a Minimum	Established as a Minimum	U.C.L.A. Source
Ponderosa pine needles	7	11.1		7.4
Madrone leaves	7	4.6		8.0
Wheatstraw	6	4.6		7.4
White fir punk	7	4.6		7.4
White fir punky logs	12	3.0		5.6
Sedge	7	4.6		5.9
Desert needlegrass	4		3.7	4.6
Joshua bark			2.4	

True minimum energy requirements for persistent ignition were determined only for desert needlegrass and Joshua bark. Other fuels were not exposed to energies less than those recorded in Table 1.

3.0 PREPARED FUELS

Prepared fuels for Operation SNAPPER were selected to cover the range of fuel conditions found in common forest cover types. In addition to homogeneous fuels described in Table 2, punk (rotten wood) and cheatgrass were added to ponderosa pine, madrone, and wheatstraw to form heterogeneous litter combinations.

Fuels, except punky logs, were arranged as fuel beds in trays 2 ft square and 2 in. thick. These trays were then covered with 2-in. mesh chicken wire to prevent blast wind from blowing needles or leaves out of the tray, and to permit vertical placement of trays. Laboratory tests showed that this wire cover does not affect ignition energies. All fuel beds were placed with one edge on the ground and fixed so their surface was perpendicular to the incidence of thermal radiation from the bomb.

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TABLE 2

Description of Fuels

Fuel	Description	Thickness (Cm)	Density (Gm/cc)	Fuel Moisture (Per Cent)	
				Shot 3	Shot 4
Ponderosa pine	*Pinus ponderosa* needles, on the ground 1-3 yrs	0.038	0.51	7.4	12.6
Coulter pine	*Pinus coulteri* needles, on the ground 1-3 yrs	0.066	0.46	7.4	11.4
Madrone leaves	*Arbutus menziesii*, freshly fallen leaves	0.028	0.45	9.0	11.9
Rhododendron leaves, dry	*Rhododendron catawbiense*, freshly fallen leaves	0.025	0.50	9.2	10.1
Rhododendron leaves, green	*Rhododendron catawbiense*, picked green from trees	0.025	0.50	8.8	13.2
Beech leaves	*Fagus grandifolia*, freshly fallen leaves	0.009	0.39	9.5	13.6
Wheatstraw	*Triticum aestivum*, leaves and heads removed	0.037	0.35	6.3	10.1
Cheatgrass	*Bromus tectorum*, cured	0.003*	0.37	7.1	10.6
Horsehair lichen	*Alectoria jubata*	0.002*	0.65	7.9	14.0
Douglas fir duff	*Pseudotsuga taxifolia*, matrix of weathered leaves & twigs with some soil & decomposed material	-	-	9.2	14.0
Hardwood punk	Various species, small pieces of rotten wood	-	-	9.2	-
White fir punk	*Abies grandis*, small pieces of rotten wood	-	0.10	8.5	15.2
Black oak punk	*Quercus kelloggii*, pieces of rotten wood	-	0.10	9.9	12.9
White fir log	*Abies grandis*, rotten logs	-	0.10	7.6	10.7
Black oak log	*Quercus kelloggii*, rotten logs	-	0.10	5.9	10.4

* Thickness of finest fuel particles

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Punky logs, 4 to 8 in. in diameter, 12 in. long, and with ½ to 1 in. of fine-shredded, rotten material on their surface, were staked to the ground. At each of the 13 stations an area 50 ft toward ground zero from the fuel beds was scraped free of vegetation and covered by 2 in. of gravel to eliminate smoke from native vegetation and reduce dust.

4.0 NATURAL FUELS

Thick clumps of grass stalks, 6 to 12 in. high, provided some protection from blast winds for the fine, dead grass leaves clustered at their bases. Bursage and jointfir were similar enough that they were evaluated as one fuel type. Grass and brush clumps were far enough apart so that fire would not spread from one to the other, and maximum ignition distances could be determined accurately. Unburned creosote bush and Joshua trees were not present in the vicinity of the target and could not be used as indicators of thermal effects for these shots.

TABLE 3

Natural Fuels Found at Nevada Proving Grounds

Fuel	Description	Thickness (Cm)	Density (Gm/cc)
Natural grass	Desert needlegrass, *Stipa speciosa*, dense mat of fine dead leaves at base - Leaves	0.007*	0.534
	- Stalks	0.098	
Brush	White bursage, *Franseria dumosa*, many dead twigs sparsely arranged	0.037 to 0.108	0.562
	Jointfir, *Ephedra* spp., many dead twigs	0.072 to 0.119	0.557
	Creosote bush, *Covillia tridentata*, few dead twigs, sparse green leaves	-	-
Joshua bark	Joshua trees, *Yucca brevifolia*, 15 to 20 ft high with thick, cork-like bark covered by old dead leaves	-	-

* Thickness of finest fuel particles

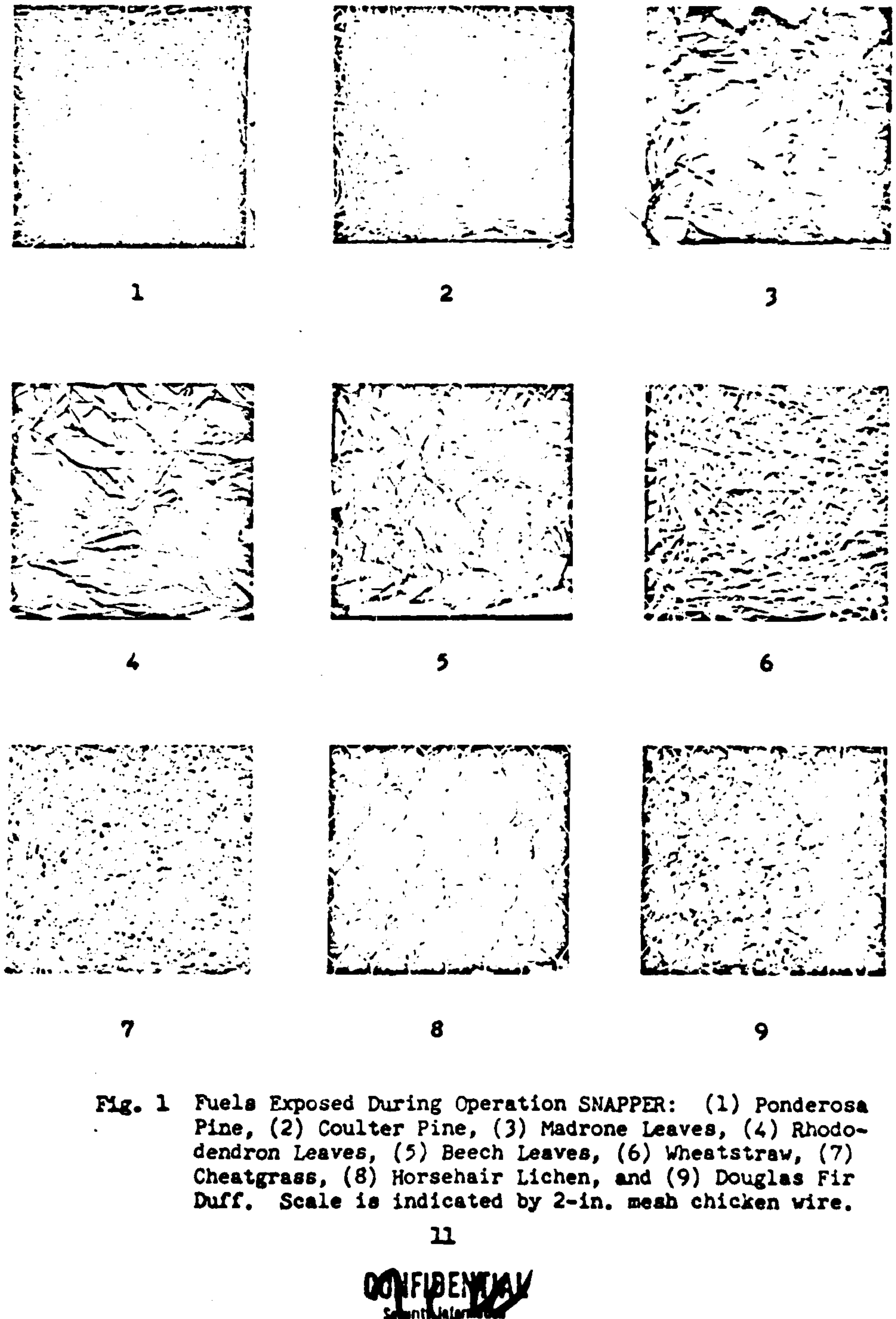

Fig. 1 Fuels Exposed During Operation SNAPPER: (1) Ponderosa Pine, (2) Coulter Pine, (3) Madrone Leaves, (4) Rhododendron Leaves, (5) Beech Leaves, (6) Wheatstraw, (7) Cheatgrass, (8) Horsehair Lichen, and (9) Douglas Fir Duff. Scale is indicated by 2-in. mesh chicken wire.

5.0 OTHER DATA

Fuel moistures at shot time were determined from duplicate fuel beds set out near Yucca Lake. Fuel temperatures approximated air temperatures at shot times.

Documentary photography of fuel beds before and after shots was provided by Los Alamos Graphic Arts. Moving pictures of ignition and combustion at three stations during each shot were made by the Army Pictorial Service Division, Office of the Chief Signal Officer.

To test the screening effect of tree crowns a series of pine plywood strips was laid perpendicular to the incidence of radiation behind the tree shown in Fig. 3. These strips were arranged to extend through the bomb shadow of the tree crown at 5-ft intervals.

Ignitibility of coniferous slash was studied on Shot 4. One tree broken on Shot 3 was left on the ground. Branches and needles from other trees broken by Shot 3 were piled in typical logging slash piles as shown in Fig. 4.

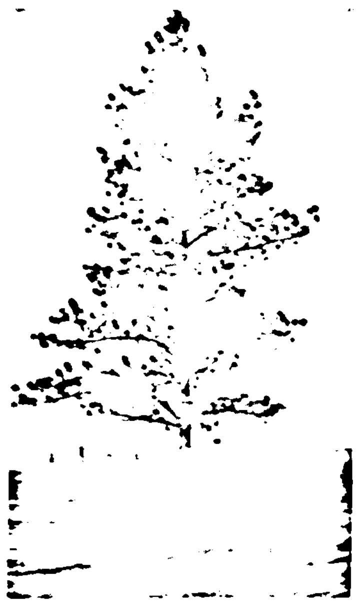

Fig. 3 Crown-Shadow Tree Showing Sparseness of Tree Crown

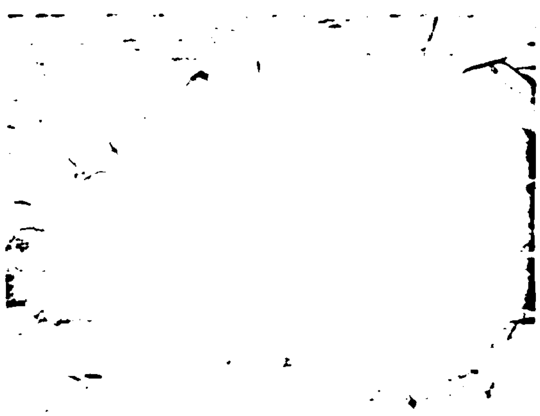

Fig. 4 Logging Slash Pile Exposed to Shot 4 — Total Thermal Energy 20 cal/sq cm

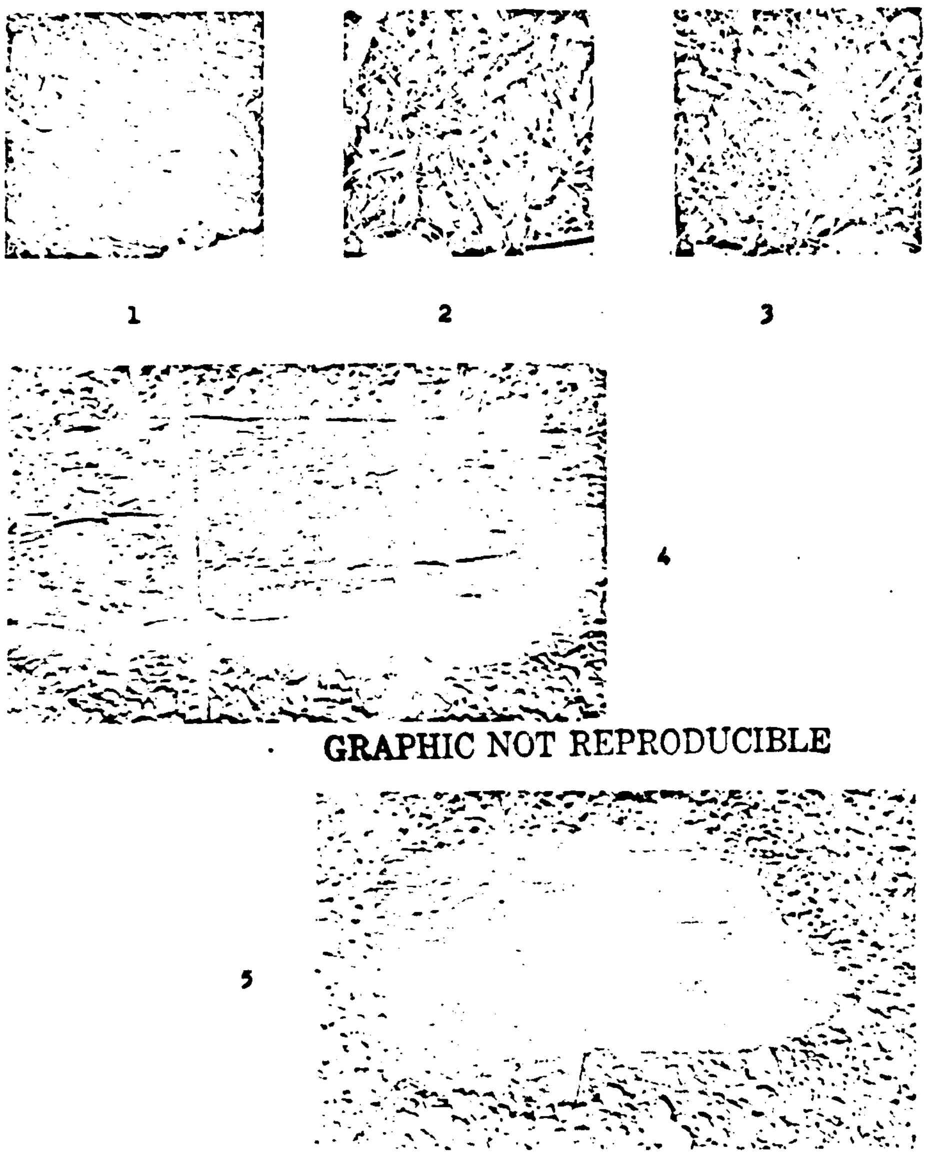

Fig. 2 Punk Fuels Exposed During Operation SNAPPER: (1) Hardwood Punk, (2) White Fir Punk, (3) Black Oak Punk, (4) White Fir Log, and (5) Black Oak Log

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5.0 OTHER DATA

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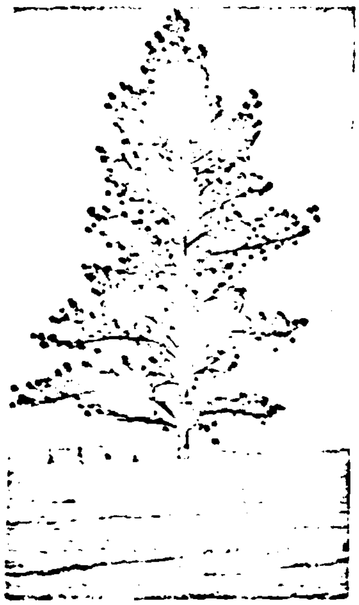

Fig. 3 Crown-Shadow Tree Showing Sparseness of Tree Crown

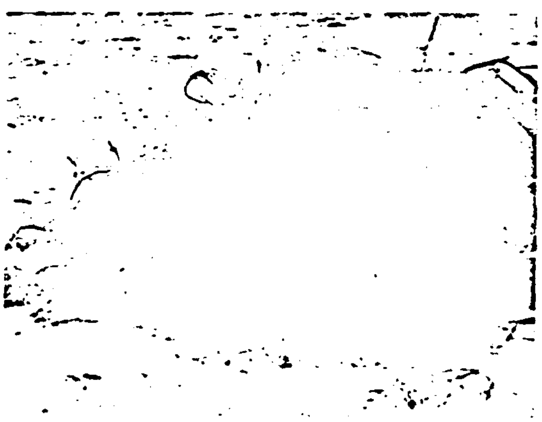

Fig. 4 Logging Slash Pile Exposed to Shot 4 — Total Thermal Energy 20 cal/sq cm

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6.0 RESULTS

Tables 4, 5, and 6 and Figures 5 and 6 summarize field observations of SNAPPER thermal effects on wildland fuels. Minimum total thermal energy for ignition was established at 8.9 calories for pine needles, 5.3 calories for hardwood leaves, 3.0 calories for grass, and 3.1 calories for punky or rotten materials.

Moisture contents of fuels at shot time are shown in Table 2. Humidity and temperature conditions which produced these moisture contents are recorded in Fig. 7. Though SNAPPER Shots 3 and 4 occurred at 0930 and 0830 PST, respectively, temperature was still rising, humidity was still falling at shot time, and resultant fuel moistures were decreasing.

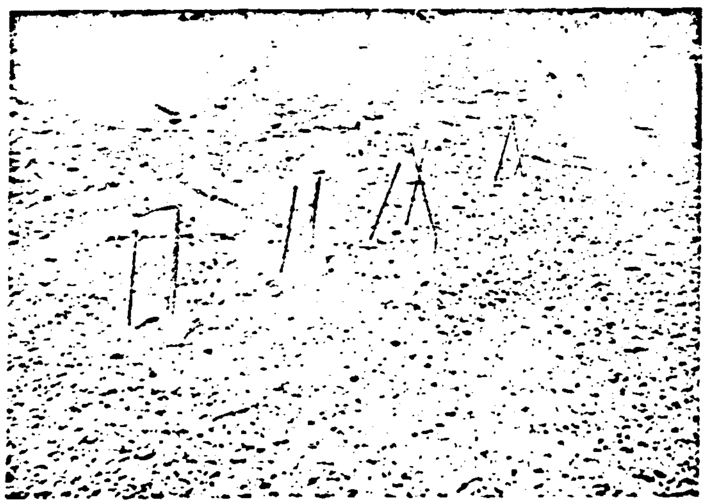

Fig. 5 White Fir Log and Beech Fuel Bed Burned on Shot 3, Total Thermal Energy 3.4 Cal/sq cm

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TABLE 4

Thermal Effects of SNAPPER Shots
on Prepared Homogeneous Fuels

Total Thermal Energy[a] (Cal/sq cm)	Shot	Thermal Effect[b]															
		Ponderosa pine	Coulter pine	Madrone	Dry Rhododendron	Green Rhododendron	Beech	Wheatstraw	Cheatgrass	Horsehair lichen	Hardwood punk	Fir punk	Black oak punk	Black oak log	Black oak log	Fir log	Fir log
22.0	3								X								
20.4	4				E												
17.0	3		E						E								
14.5	4					E				B							
13.5	3	B	B														
10.8	4	B	C	B			E	B		C							
10.8	3	B	B		E	E											
8.9	3	B	B	C	C	C		C		B							
8.2	4	C	C	C	C	C	E	E	E	C							
7.3	3	C	C	B	C	C	C	C		E					B	B	
6.6	4	N		B	C	C	B		B	B	B		B		B	B	
6.1	3	C	C	C	C	C	C	C	B	E			B	B	B	B	B
5.3	4	N		N			B	C	C	B	B		B		B	B	
5.1	3			C	C	C	C	N	B	E		B		B	B	B	B
4.4	4					N	C		C	C	B		B	C	C	B	C
4.3	3			N			C	N	B	C	C		B	B	C	N	B
3.7	4						C		N	N	B	B	B	N	N	N	B
3.4	3						B	N	N	N		B	B	N	N	B	N
3.1	4								N	N		B	B	N	N	N	B
2.7	3								N	N	N		N	N	N	N	N
2.5	4								N	N		N	N	N	N	N	N
2.1	3								N	N		N	N	N	N	N	N
2.0	4								N	N			N	N	N	N	N
1.6	3								N	N			N	N	N	N	N
1.6	4								N				N	N	N	N	N
1.3	4																

[a] U. S. Naval Radiological Laboratory. Thermal Radiation From a Nuclear Detonation. Project 8.3 Operation SNAPPER Report (rough draft). Tables 4.3 and 4.4.

[b] N - No visible effect
C - Charring
B - Fuel consumed by burning
X - No evidence--unknown
E - Ignited but extinguished by blast

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TABLE 5

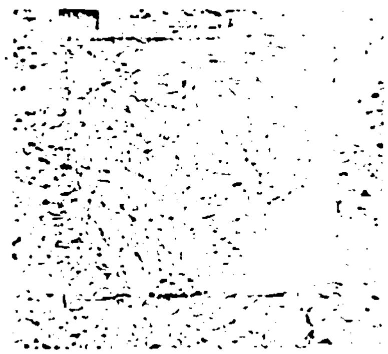
Thermal Effects of SNAPPER Shots
on Prepared Heterogeneous Fuels

Total Thermal Energy [a] (Cal/sq cm)	Shot	Thermal Effect [b]						
		Ponderosa pine, punk	Coulter pine, grass	Rhododendron, punk	Rhododendron, grass	Wheatstraw, punk	Horsehair lichen, punk	Douglas fir litter
10.8	3							B
8.9	3							B
8.2	4						B	
7.3	3							B
6.6	4	N	B	E	B	B	B	
6.1	3							B
5.3	4	N	N	N	N	C	B	C
5.1	3							C
4.4	4	N	N		C	N		B
4.3	3							B
3.7	4							N
3.1	4							B
2.5	4							N

[a] U.S. Naval Radiological Laboratory. Thermal Radiation From a Nuclear Detonation. Project 8.3 Operation SNAPPER Report (rough draft). Tables 4.3 and 4.4.

[b] N - No visible effect
C - Charring
B - Fuel consumed by burning
E - Ignited but extinguished by blast

Hardwood Punk Burning at H+2 Hours Following Shot 4, Total Thermal Energy 4.4 Cal/sq cm



Wheatstraw Charred on Shot 3, Total Thermal Energy 8.9 Cal/sq cm

Fig. 6 Illustrations of Thermal Effects

TABLE 6

Minimum Ignition Energies for Natural Fuels — SNAPPER Shot 3[a]

Fuel	Thermal Energy[b] (Cal/sq cm)
Natural grass	3.0
Joshua bark	4.1

[a] There was no unburned vegetation for Shot 4.

[b] U.S. Naval Radiological Laboratory. Thermal Radiation From a Nuclear Detonation. Project 8.3 Operation SNAPPER Report (rough draft). Tables 4.3 and 4.4.

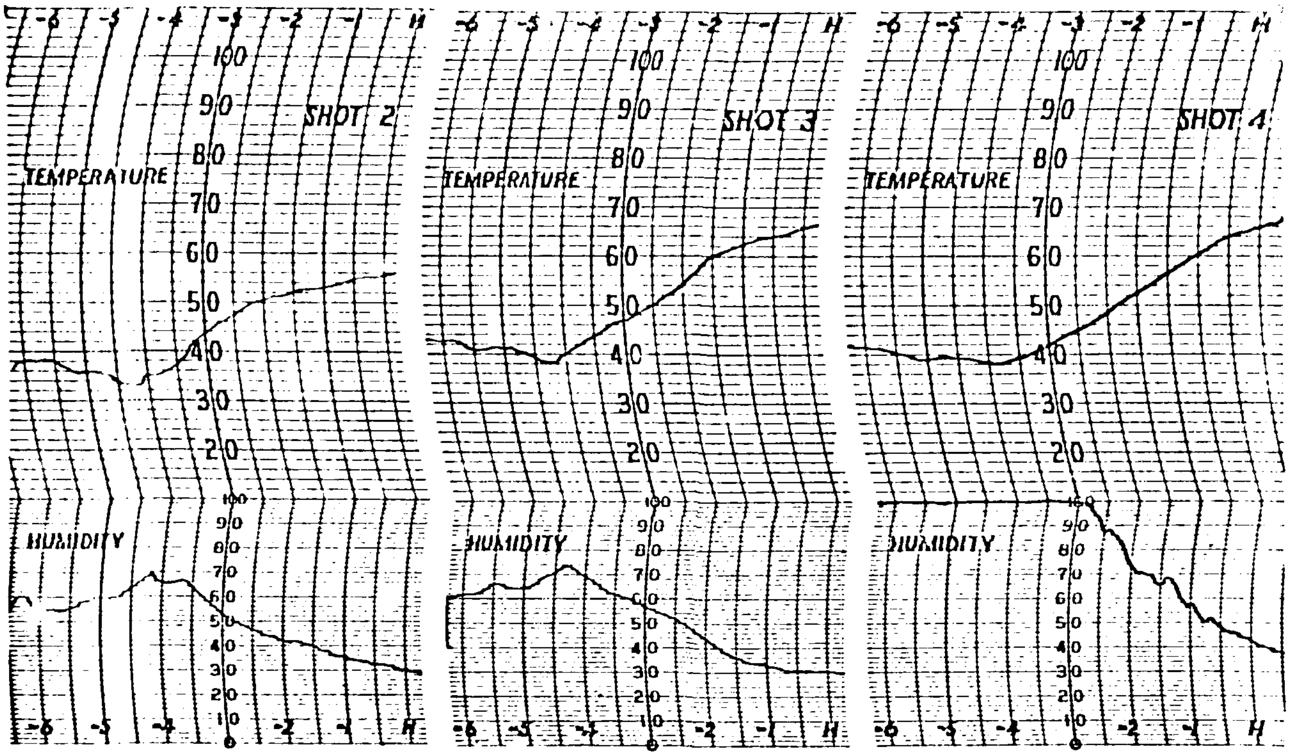


Fig. 7 Temperature and Relative Humidity Records H-6 Hours to H-Hour, SNAPPER Shots 2, 3, and 4. Forest Service Fire Weather Station 20,000 ft in Area 7.

6.0.1 Blast-wave Effect on Persistence of Ignition

Blast winds extinguish some fires which otherwise would continue to burn until the fuel is consumed. This extinguishment appears to occur in grass and other fine fuels when peak particle velocity is greater than 120 fps and in thicker fuels such as pine needles when this velocity is greater than 170 fps. These peak particle velocities are associated with peak overpressures of 2.2 and 3.0 psi respectively.

Table 4 shows considerable scatter in location of fuel beds where persistent ignition was considered to be extinguished by blast winds (recorded "E"). This scatter occurs partly because the phenomenon itself depends on fuel compactness and arrangement and partly because it is difficult to determine whether char is due to transient ignition or to persistent ignition extinguished by blast.

Identification of char caused by persistent ignition, extinguished by blast, was based on presence of traces of white ash on fuel surface. Char due to transient ignition which died out with the fireball left only a black scorched surface. Some observations were checked against motion picture records, but these were not always reliable because the pictures could not record glowing embers or small pin points of flame.

Effects of fuel characteristics and burning time on blast-wind extinguishment are now being investigated in the laboratory in order to derive more consistent relationships and to explain some of the scatter found in Table 4.

6.0.2 Comparison with Laboratory Source Tests

Fuels exposed during Operations BUSTER and SNAPPER were also exposed to the Forest Service 12-inch laboratory source at U.C.L.A. Data for comparable fuel conditions (Table 7) indicate that energy required for ignition of forest fuels by laboratory source averages 21 per cent greater than that required by bomb source.5/ These higher energies required by laboratory source can be explained largely by differences in spectral distribution of energy and in pulse shape. The laboratory source is operated at 5,000° F, at which temperature 60 per cent of the energy is emitted at wave lengths longer than 1.2 microns. Higher bomb temperatures move both peak energy output and total distribution to shorter wave lengths (50 per cent of total energy is emitted at wave lengths shorter than 0.7 microns) which more closely approximate those at which maximum absorptance in forest fuels occurs. Data are not yet available for computing these correction factors or for evaluating effects of pulse-shape differences.

5/ Wilcoxon sum technique, used to test the hypothesis that there is a real 21 per cent difference between required laboratory source and bomb energies, showed that such a difference is statistically highly probable.

TABLE 7

Relationship Between Minimum Ignition Energies by Atomic Bomb Source and by Laboratory Source

Fuel	Shot	Moisture Content (Per cent)	Minimum Ignition Energy(E) Bomb (Cal/sq cm)	Minimum Ignition Energy(E) Laboratory (Cal/sq cm)	E (Lab) ÷ E (Bomb)
Desert needle-grass	BUSTER Easy	4	3.7	4.6	1.24
Cheat grass	SNAPPER 3	7.1	4.3	5.9	1.37
Cheat grass	SNAPPER 4	10.6	6.6	6.2	.94
Beech	SNAPPER 3	9.5	3.4	4.3	1.27
Beech	SNAPPER 4	13.6	5.3	5.3	1.00
Lichen	SNAPPER 4	14.0	5.3	5.4	1.02
White fir punk	SNAPPER 3	8.5	3.4	4.4	1.29
Black oak punk	SNAPPER 3	9.2	3.4	3.6	1.05
Black oak punk	SNAPPER 4	12.9	3.1	4.1	1.32
White fir log	SNAPPER 3	7.6	3.4	4.2	1.24
White fir log	SNAPPER 4	10.7	3.1	4.7	1.52

There is considerable variation among individual difference values as shown in Table 7; the standard deviation of these individual values is 18 per cent. These variations appear to be normally distributed and to arise from several factors associated with the following experimental techniques:

1. Both laboratory and bomb tests expose fuels only to discrete energy levels of approximately one-half calorie or greater. Therefore the true minimum energy required to ignite any particular fuel is usually less than that recorded.

2. Probability of ignition at minimum energy levels, associated with compactness and moisture content variations, affects accuracy of laboratory and field data as discussed on page 21.

3. Small errors in moisture content determination and discrepancies in energy measurement also increase variation in individual values shown in Table 7.

Table 8 indicates ranges of possible error in minimum ignition energies associated with experimental techniques described above.

TABLE 8

Magnitude of Errors Associated With Determination of Minimum Ignition Energy

Source of Error	Error (Cal/sq cm)	
	Bomb	Laboratory
Discrete energy level exposure[a]	0.0 to 0.8	0.5
Variations in fuel bed[a]	0.0 to 0.8	0.5
Moisture content determination[b]	0.4	0.4
Total energy evaluation[c]	0.5	0.5

[a] Based on an inspection of energy levels and thermal effects given in Table 4 and on experimental procedure used in laboratory tests.

[b] Based on: Buck, Charles C. and Hughes, John E. "The Solvent Distillation Method for Determining the Moisture Content of Forest Litter," Journal of Forestry XXXVII (1949), 649; and laboratory source tests which indicate that a change of one per cent in moisture content in dead forest fuels is associated with an inverse change of 0.2 calories in minimum total energy required for ignition.

[c] Based on estimates that actual total energy which impinges on any one fuel sample is probably within 10 per cent of the measured or accepted value for that station.

6.0.3 PROBABILITY OF IGNITION AT MINIMUM ENERGY LEVELS

Forest fuel beds, even when made up of one kind of leaf or needle, are at best a heterogeneous collection of various sizes of fuel particles of varying moisture content (unless humidity and temperature have been constant for several hours) and arranged in an infinite variety of patterns and degrees of compactness. At minimum energy levels there may be only one small spot in a fuel bed or on a punky log where the

size, arrangement, and moisture content of fuel particles is just right for ignition by the particular intensity-time pulse which acts on the fuel. Actually, in a 2-ft square fuel bed or on one punky log there may be no "right spot," in which case with one fuel bed per station no ignition may occur. This phenomenon is illustrated by the fact that on both SNAPPER shots only one of two white fir logs ignited when total energy was approximately 3 cal/sq cm.

This effect is important for evaluation of results from prepared fuel beds and in explaining apparent inconsistencies in data of Tables 4, 5, and 6. In natural wildland fuels this effect reduces the number of ignitions per acre as illustrated by the burning of natural grass clumps in Area T-7 — for near the maximum ignition distance, less than one grass clump in 200 burned.

6.0.4 SCREENING EFFECT OF GREEN FOLIAGE

Moisture content of green leaves and needles from living tree and brush species and from green grass normally is near or above 100 per cent based on oven-dry weight of plant material. This water prevented ignition of green material when exposed to total thermal energies as high as 22 calories. Moisture content of green pine needles on standing trees cut 3 weeks was 93 per cent prior to Shot 3. Just after Shot 3 those same needles which had a clear view of the fire ball were turned brown and had a moisture content of 71 per cent. Needles just behind the screen of foliage nearest the fire ball were unaffected.

Branches and foliage from trees broken by Shot 3 were piled into typical logging slash piles for Shot 4. These were not ignited by total energies of 20 cal/sq cm because moisture content was 70 per cent.

Screening effect of green foliage was studied in another way by observing the shadow effect of the tree crown in Fig. 3 on Douglas fir plywood strips laid so as to extend through the tree crown shadow from the fire ball at 5-ft intervals. Boards in the crown shadow showed no evidence of charring, while parts of boards extending beyond the crown shadow showed heavy charring.

CHAPTER 5

7.0 CONCLUSIONS

1. Ignition of punky and fine grassy fuels can be expected from atomic explosions whenever total thermal energies exceed 3 cal/sq cm, assuming fire weather conditions6/ and pulse shapes7/ similar to BUSTER and SNAPPER shots.

2. Minimum ignition energies have been established approximately within plus or minus 10 per cent for common wildland fuels — pine needles, hardwood leaves, grasses, and punky materials.

3. SNAPPER results and laboratory tests indicate that no more large-scale forest-fuel effects tests are required for bombs with thermal-pulse times of the order encountered in BUSTER and SNAPPER shots. Minimum ignition energies are accurate enough for operational uses, and if additional data are required for other wildland fuel types, laboratory source tests may be employed.

4. Punky (rotten) materials and fine grasses which are ignited at low-energy levels by atomic explosions spread fire to associated fuels which would not otherwise have been ignited. Since most forest fuels have some associated punk or grass, range of ignitions from ground zero is determined by extent of minimum energy required to ignite these critical fuels or small critical spots in other fuels rather than energy required to ignite heavier fuels.

5. Sparse tree crowns exposed as at Operation SNAPPER to energies of 22 cal/sq cm effectively shade dead surface fuels so that few ignitions of these fuels can occur in their shadows. Dense, green forest stands with 100 per cent crown closure should offer few if any ignitible points where persistent ignition and fire would occur following atomic explosions.

6. Minimum thermal energies from atom bombs required to ignite wildland fuels can be approximated by laboratory source tests when corrections are made for pulse shape and spectral distribution.

6/ Relative humidity less than 40 per cent, air temperature greater than 35° F, and fuel moisture less than 15 per cent.

7/ Atomic weapons which produce thermal-intensity-time histories similar to those of Operations BUSTER and SNAPPER shots.

7. The probability that ignitions will occur when fuels are located where they receive the minimum thermal energy required for ignition depends on moisture content, thickness, thermal conductivity, specific weight, and arrangement of fuel particles in the fuel bed.